NEURAL NETWORKS IN ANTENNA ENGINEERING – BEYOND BLACK-BOX MODELING

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Abstract **- Recently neural networks have been applied in antenna modeling where the role of the network is not just for black-box modeling. This paper highlights that aspect of neural networks from the antenna engineering application point of view.**

I. Introduction

During the last decade there has been a growing interest in applying neural networks (NN) to antenna analysis and design. In the first few years, the emphasis was on developing black-box CAD models. Data were generated either from other simulation tools or from experiments. The NN model next was used to generalize these data and used mainly as an interpolation tool for CAD. But in the recent years the role of NN in antenna engineering is not just to implement black-box modeling. It is now applied as a conventional method in computational electromagnetics where no closed form solutions or models exist, or when a real-time optimization approach is desired. This paper emphasizes the role of NN as a beyond black-box modeling tool in antenna engineering.
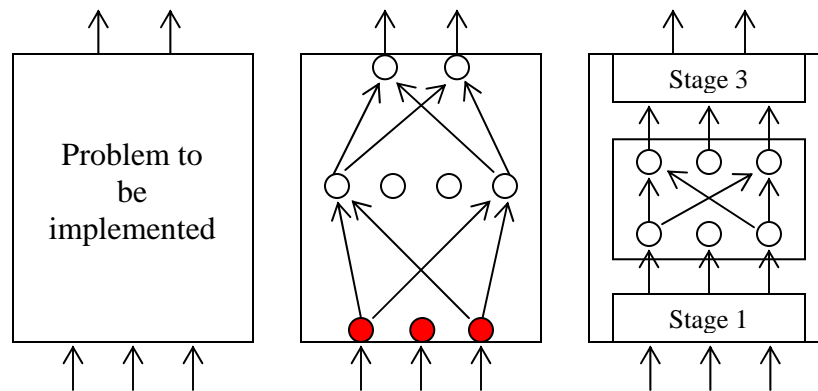
II. Issues is Neural Network Modeling

Fig. 1: Problem at hand can be modeled using neural networks as a whole where it works as a black-box, or NN can be used to model a part of the whole problem

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The problem in hand either can be implemented in total using NN or the whole problem can be divided into different parts and NNs can be used to implement separate aspects of the complex problem. By implementing the problem in its totality, the NN acts as a black-box and does not disclose the physics behind it to the end user. On the other hand, partial implementation with NN preserves the background phenomena of the problem to some extent. This aspect of NN is described in Fig. 1. The knowledge based neural network also preserves the background physics of the problem to some extent. In some cases the existing prior knowledge is used to train the network.

II. Computational Electromagnetics Applications

Several analytical and numerical methods have been suggested over the years for antenna modeling. Some of the drawbacks of these methods are the computation speed and/or the demand on computer storage. Recently, NN has been applied in conjunction with these methods. The basic purpose is to reduce the computation time and the storage space.

The Method of Moment technique requires the evaluation of the Green's functions. Radial basis function neural networks are employed for fast and efficient calculation of Green's functions in layered medium [1]. The model takes the frequency as an input and provides the expansion parameters of the Green's function as outputs. The proposed NN model is very convenient for the full-wave planar solvers based on the integral equation formulation, because complete information about a Green's function over a wide frequency band can be stored in the form of weights of the associated NN.

The precision of Finite Element Method depends on developing proper meshing for the antenna structure under construction. Automatic mesh generation procedures using neural networks have been developed in the recent years [2-4]. The main advantage of these neural approaches lie in the good quality of the meshes obtained and in its simplicity. Good accuracy solutions are possible with these neural models with a lower computational effort than a full adaptive mesh generation process.

Novel methods using NNs are described in handling the singularities of the Green's functions in the Spectral Domain Analysis of patch antennas [5]. The technique named Neurospectral method approximates a function $f(x,y)$ as per the equation below, where $f(x,y)$ is a function with singularities at (x_i, y_i), in the ranges of x and y, and $g(x,y)$ is a continuous function such that $g(x,y) = f(x,y)$ at all nonsingular points of $f(x,y)$.

$$f(x,y) = g(x,y) + \sum_i g(x,y)\delta(x - x_i)\delta(y - y_i)$$

Using NN it is possible to find out continuous functions. Using this procedure closed form expressions for the Green's functions can be obtained.

Neural networks have also been used in conjunction with the FDTD approach. The leapfrog based FDTD technique requires a long computation time. The concept of NeuroFDTD has been proposed recently [6] to alleviate these problems. In this, a NN with a cost function formed using wave equation in FDTD form has been suggested.

III. Other Applications

In response to the ever-increasing needs of antenna bandwidth, considerable amount of effort is currently underway to develop multiband antennas. Reconfigurable multiband

antennas are attractive for many applications where it is desirable to have a single antenna that can be dynamically reconfigured to transmit and/or receive on multiple frequency bands. Mostly planar designs are preferred for these structures due to their added advantage of small size, low manufacturing cost and conformability. The technology of design and fabrication of microelectromechanical systems (MEMS) for RF circuits has put a major positive impact on reconfigurable antennas as shown in Figure 2.

Due to the multiscale nature of reconfigurable antennas, a single analytical method cannot characterize the whole structure. For accurate modeling of these structures, the switches, the feeding network and the radiating elements need different numerical computation techniques, leading to a computationally challenging task.

Even more challenging job is to determine the reconfigurable structure in a large array, for the antenna to radiate at the user desired operational frequencies. Recently, this task has been effectively handled by using neural networks [7]. The problem is approached as a classification type of problem and handled by using a self-organizing mapping neural network. The paradigm of application is shown in Figure 3. An approximate reconfigurable structure can be obtained using this approach.
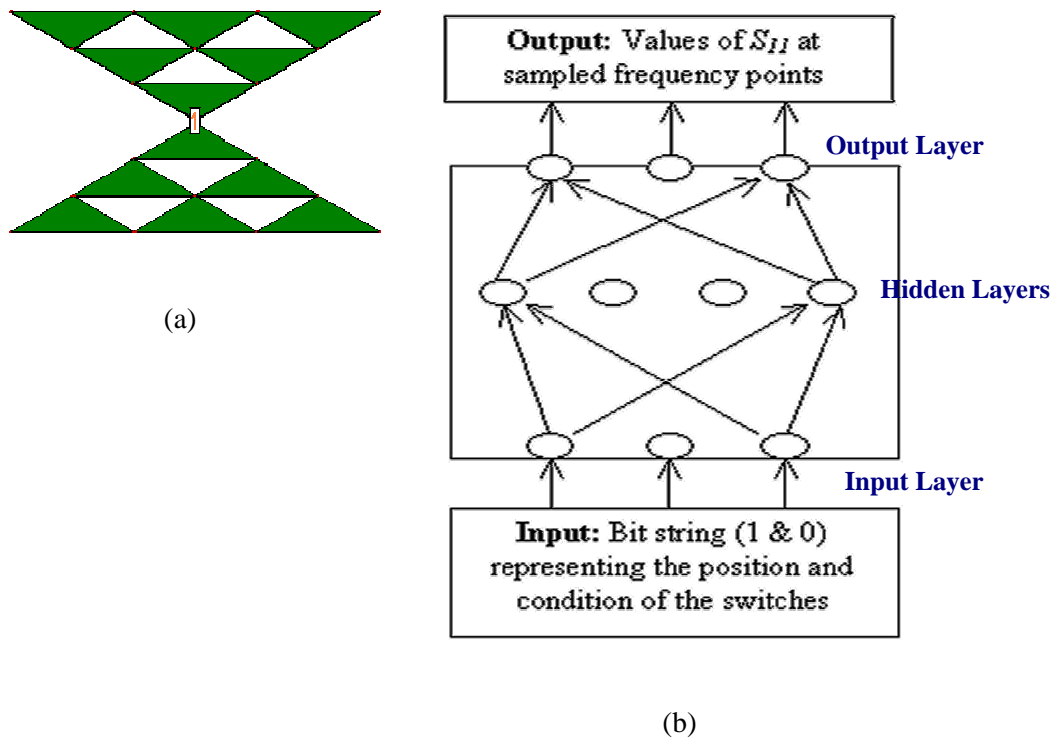

(a)

(b)

Fig. 2.   (a) Fractal antenna connected by switches. There are 70+ configurations depending on which elements are active and how they are fed. (b) Neural network used in the analysis of the antenna
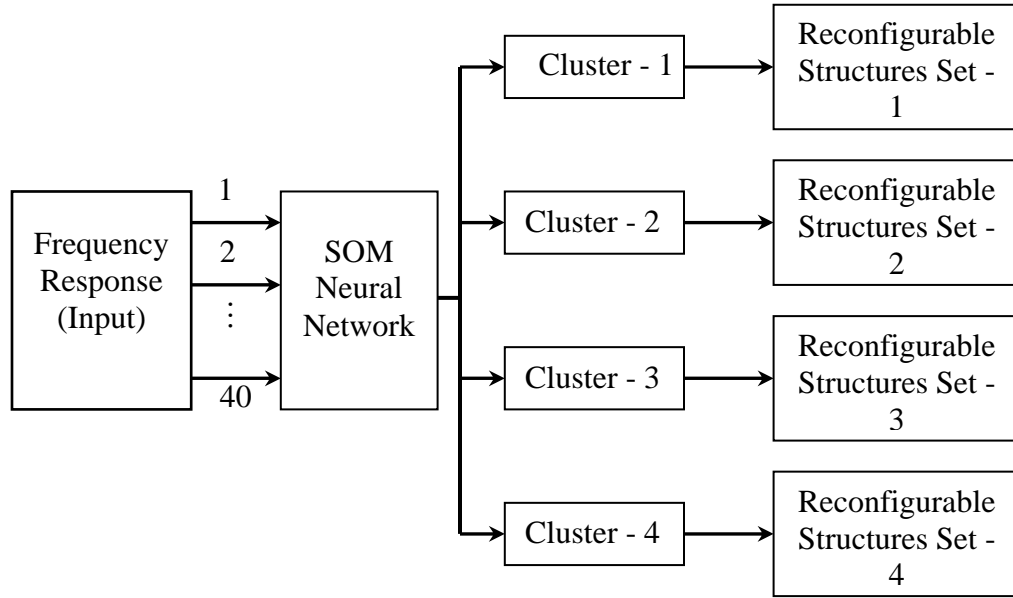
Fig. 3. Paradigm of reconfigurable structure design

The developed methodology can be extended for the design of any reconfigurable electromagnetic structure.

IV. Conclusions

This paper describes that aspect of NN from view point of antenna applications. The role of NNs in computational electromagnetics has been described, where NNs are used to expedite the present analytical/numerical techniques used for antenna modeling. Recent application of NN for reconfigurable antenna structure determination has also been described.

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